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# "Control of a Flexible Beam Using Fuzzy Logic"

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## Introduction

The goal of this project, funded under the NASA Summer Faculty Fellowship program, was to evaluate control methods utilizing fuzzy logic for applicability to control of flexible structures. This was done by applying these methods to control of the Control Structures Interaction Suitcase Demonstrator developed at Marshall Space Flight Center. The CSI Suitcase Demonstrator is a flexible beam, mounted at one end with springs and bearing, and with a single actuator capable of rotating the beam about a pin at the fixed end. The control objective is to return the tip of the free end to a zero error position (from a nonzero initial condition). It is neither completely controllable nor completely observable.[1] Fuzzy logic control was demonstrated to successfully control the system and to exhibit desirable robustness properties compared to conventional control.

## Fuzzy Logic

"Fuzzy" logic, which was initially developed by Lofti A. Zadeh of Berkeley, is a combination of multi-valued logic, probability theory, and artificial intelligence. It incorporates the imprecision inherent in many real-world systems, including human reasoning, by allowing linguistic variable classifications such as "big," "slow," "near zero," or "too fast." Unlike binary logic, fuzzy systems do not restrict a variable to be a member of a single set, but recognize that a given value may fit, to varying degrees, into several. For example, a speed of 55 mph may be moderately slow, fast, or too fast depending on other factors such as speed limit or road condition.

Fuzzy systems operate by testing variables with IF-THEN rules, which produce appropriate responses. Each rule is then weighted by a "Degree of Fulfillment" of the rule invoked; this is a number between 0 and 1, and may be thought of as a probability that a given number is considered to be included in a particular set. A wide variety of shapes is possible for fulfillment functions, triangles and trapezoids being the most popular.[2] Fulfillment functions for this study were of the form

$$\mathrm{fuzzy}(x,m,s,p)=\exp(-(|x-m|/s)^p) \qquad (1)$$

where m,s,and p are user-chosen parameters and x is the value to be tested. This function was chosen because of its flexibility; by changing "m," "s," and "p" whole families of different functions can be obtained. A sample of the functions obtained by varying the "p" parameter is shown in Figure 1. The system operates by testing rules of the type

"If error is big and velocity is small,
then u should be negative and big."

The degree of fulfillment for such a rule is the minimum of the degrees of fulfillment of the antecedent clauses; i.e.,

$$DOF = \min\,[DOF_{\text{error big}},\ DOF_{\text{velocity small}}]. \qquad (2)$$

The total output of the control system is a weighted sum of the responses to all "n" rules

$$u = \left({}_{i=1}\Sigma^{n}\, w_i\,(DOF_i)\,B_i{}^{d}\right)/\left({}_{i=1}\Sigma^{n}\, w_i\,(DOF_i)\right) \qquad (3)$$

where $DOF_i$ is the degree of fulfilment of rule "i," $B_i{}^d$ is the "defuzzified" output response to rule "i," and $w_i$ is a weight indicating the relative importance of rule "i."[3]

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## The Basic Fuzzy Control System

A simulation of the CSI Suitcase Demonstrator was implemented on a 386 PC equipped with MATLAB. The two measurable quantities at the system output are line of sight error and angular rate of change. Fuzzy categories assigned to each were positive-big, positive-medium, positive-small, zero, negative-big, negative-medium, and negative-small. In addition, LOS error has a "near-zero" category (see Figure 2 for category examples). A standard fuzzy control system was generated using 14 rules. The rules for the initial system were of two types

Set A: If LOS error is positive-big, then u is negative-big. (7 rules, one for each category of LOS error)

Set B: If LOS error is near-zero and velocity is positive-big, then u is negative-big. (7 rules, one for each category of angular velocity)

The rules in set A approximate a proportional control scheme; set B approximates derivative control, but is only effective when LOS error is small. This strategy is to drive the system to the desired output as quickly as possible, and only apply damping when the system response is close to the desired value. This was demonstrated to be successful in [3]. A wide variety of fuzzy system responses can be generated by changing "s," "p," and the weights of the rules. The optimal choice of system parameters, weights, etc. would depend on the desired performance characteristics for the system to be controlled; criteria used in this study for "good" control were smooth system performance, quick convergence of LOS error to 0, and small overshoot. The unforced response of the system is shown in Figure 3, and a typical fuzzy system response is given as Figure 4. Removing the "near zero" condition on the second set of rules resulted in slightly slower system response with less overshoot, as expected. Various "p" values were tried, with p=2 appearing to be optimal (lower values allowed more overshoot, and higher values resulted in failure to damp out some of the system frequency components). Changing "s" factors demonstrated that acceptable system performance is still obtained when spread is increased by as much as 100% (though overshoot increases as the factor is increased), while a relatively small (25%) decrease again leads to undamped frequency components (as higher "p" values have smaller spread, this is consistent with the results for changing "p"). Thus great overlap between sets is acceptable, while too little overlap gives less optimal results. A slightly smoother response, with no appreciable change in settling time, was obtained by averaging the control over 2, 3, or 4 time steps. The system was found to behave adequately when randomly chosen plant matrix parameters were altered by + or - 50%, and when Gaussian noise was added to system states.

## Anticipatory Fuzzy Control

A new control strategy, called anticipatory fuzzy control, was developed under this program. This differs from traditional fuzzy control in that once fuzzy rules have been used to generate a control (as in equation (3)), a predictive routine built into the controller is called to anticipate the effect of the proposed control on the system output. If using the current control value will result in system behavior which is in some way unacceptable, additional rules are called. This method may be used to nest as many sets of rules as the designer desires. Advantages of this approach compared to standard fuzzy controllers are

1. Nesting rules allows use of only as many rules as are necessary to achieve desired system performance, resulting in savings in computer run time.
2. By predicting system performance, controls which would result in unstable or unacceptable system performance can be eliminated.

Standard predictive fuzzy control, which uses only predictive rules, requires more calls to the predictive routine than this scheme, and fails to take advantage of all system knowledge.[4] The simplest type of anticipatory system control has a single additional rule of the form

"If the current value of the control ($u_0$) will cause the difference between the current and anticipated values of velocity to be 'big,' then

$$u = u_0(1 - \beta * \text{bigt}),\text{"} \tag{4}$$

where $\beta$ is a user-chosen parameter between 0 and 1, and "bigt" is the fulfillment function for the anticipated difference in velocity values (which is proportional to the predicted acceleration of the system.) A typical response with $\beta$=.7 is shown in Figure 5. Higher values of $\beta$ result in smoother responses with slightly more overshoot; lower values resemble the nonanticipatory response (Figure 4). In every case, the anticipatory fuzzy system results in smoother system response than the traditional fuzzy control. Conclusions on the effects of changing "p" and "s" hold for the anticipatory system as well. Averaging control over two or more steps had a more marked effect on the anticipatory system, with the best response (shown in Figure 6) resulting when control was averaged over two time steps. When plant parameters were perturbed, as discussed earlier, the system exhibited a larger overshoot, but still settled to 0 within 3 seconds. In contrast, a standard linear quadratic regulator had considerably less overshoot, but failed to drive the system to 0 within 5 seconds. The anticipatory fuzzy system tolerated added state noise much better than the LQR, in which the noise caused a wide excursion from the desired LOS error value of 0.

Similar system responses can be achieved using a more complex, but more intuitively satisfying, anticipatory system with several additional rules of the form

"If $u_c$ is positive big and a positive big u will make the change between current and anticipated values for velocity "big," then u is positive medium."

Effects of these rules are added in to the sums in equation (3). However, this method offers no improvement in performance over the simpler anticipatory system, while requiring more calls to the predictive routine, and therefore more computer run time.

## Conclusions

Fuzzy control methods have been demonstrated to adequately control the CSI Suitcase Demonstrator. A new type of anticipatory fuzzy controller has been developed, and has been demonstrated to exhibit desirable output properties. The fuzzy controllers have been shown to be robust in the fact of added noise and perturbations in plant parameters. It is my conclusion that fuzzy contollers show great promise for use in contol of flexible structures and should be further evaluated.

## References


[1] Sharkey, J., Private Communications, MSFC, July 1991.

[2] Self, K., "Designing with Fuzzy Logic," IEEE Spectrum, November 1990.

[3] Chiu, S., Chand, S., Moore, D., and Chaudhary, A., "Fuzzy Logic for Control of Roll and Moment for a Flexible Wing Aircraft," IEEE Control Systems, June 1991.

[4] Miyamoto, S., Yasunobu, S., and Ihara, H., "Predictive Fuzzy Control and Its Application to Automatic Train Operation Systems," Analysis of Fuzzy Information, J. C. Bezdek, ed., CRC Press Inc., Boca Raton, FL, 1986.

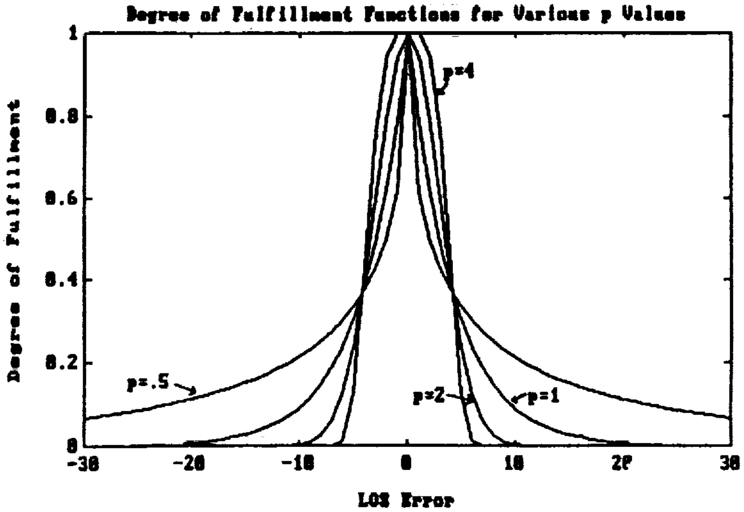


Figure 1

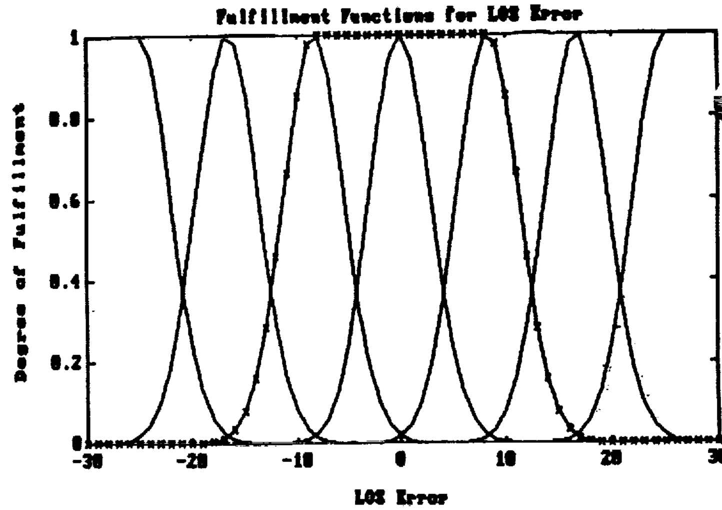


Figure 2

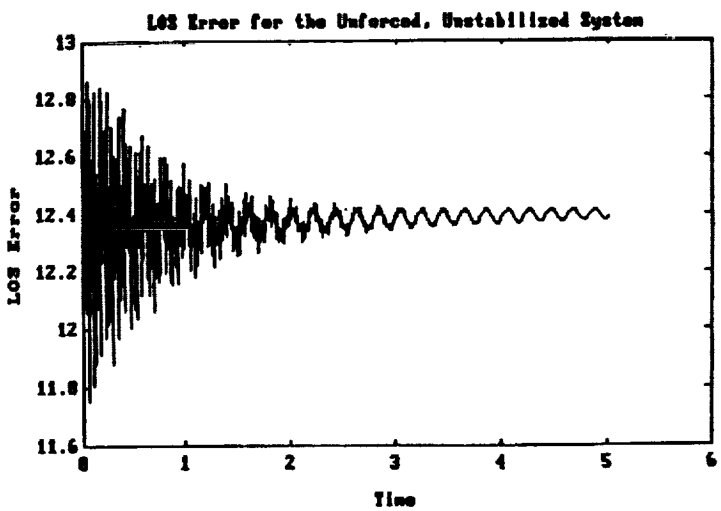


Figure 3

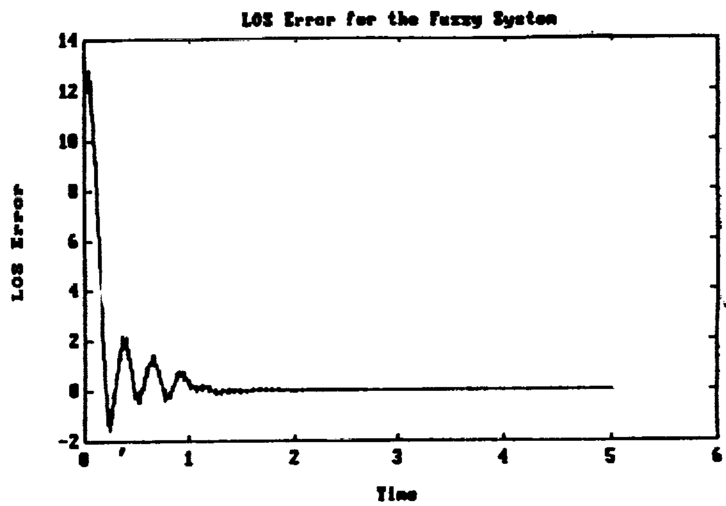


Figure 4

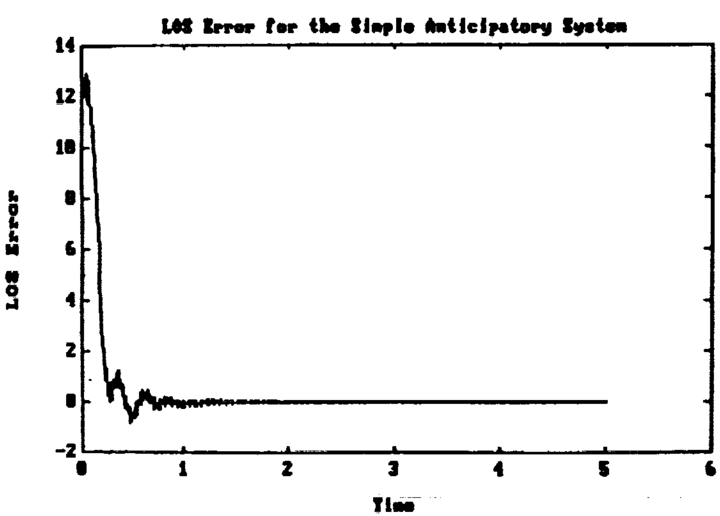


Figure 5

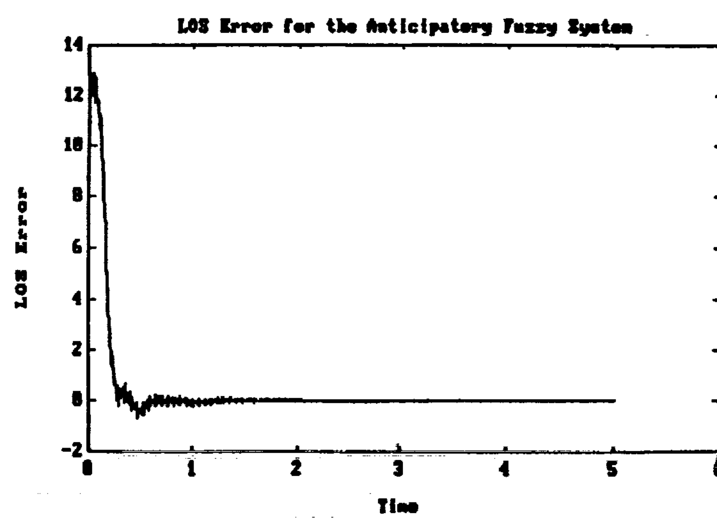


Figure 6